



Better Organization or a Source of Distraction? Introducing Digital Peer Feedback to a Paper-Based Classroom

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ABSTRACT

Peer feedback is a central activity for project-based design education. The prevalence of devices carried by students and the emergence of novel peer feedback systems enables the possibility of collecting and sharing feedback immediately between students during class. However, pen and paper is thought to be more familiar, less distracting for students, and easier for instructors to implement and manage. To evaluate the efficacy of in-class digital feedback systems, we conducted a within-subjects study with 73 students during two weeks of a game design course. After short student presentations, while instructors provided verbal feedback, peers provided feedback either on paper or through a device. The study found that both methods yielded comments of similar quality and quantity, but the digital approach provided additional ways for students to participate and required less effort from the instructors. While both methods produced similar behaviors, students held inaccurate perceptions about their behavior with each method. We discuss design implications for technologies to support in-class feedback exchange.

Author Keywords

In-class activities, peer feedback; interactive learning techniques; computer-supported collaborative learning

ACM Classification Keywords

K.3.1. Computer Uses in Education: Collaborative Learning; H.5.3 Group and Organization Interfaces: Computer-supported cooperative work.

INTRODUCTION

Learning to give and receive feedback helps students build a core skillset for project-based education [1,5]. Feedback from instructors can help students align their work with evaluation rubrics [26] and think critically about how others

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view their work [7]. Many instructors use peer feedback to help students receive more feedback, and in a more timely manner than from the instructor alone (e.g. [13]).

Classrooms currently implement peer feedback in a variety of ways, but each of these methods have challenges. Verbal feedback techniques, such as question & answer periods or open design critiques, allow the entire group to hear all the feedback given. However, in many classes, whether due to time constraints or social anxiety, not everyone gets to speak. Verbal feedback can also be easy to forget unless written down or recorded.

Written feedback, such as typing comments into an email or filling out paper evaluation forms, allows every peer to give feedback privately and in parallel, so the time required to give feedback does not need to scale to accommodate larger classes. However, these strategies do not give peers the ability to see feedback already given by other peers. Further, handwritten feedback can sometimes be illegible and difficult to organize.

A number of digital peer feedback systems have emerged to help collect and organize written feedback [5,13,21]. Courses typically use peer feedback systems outside of class time, which creates extra work for students and can take time away from reflecting on and improving their work [13]. As a solution for this, some researchers have explored using feedback systems *during* class to gather relevant, copious, timely, and diverse feedback [6,20]. However, prior work has not sufficiently explored the potential drawbacks of digital in-class peer feedback. For example, bringing new technologies into a classroom might be distracting for students and unwieldy for instructors.

Instructors lack guidance on the efficacy of using devices to facilitate in-class peer feedback and how this compares to other real-time feedback methods. Therefore, this study investigates if a digital peer feedback system produces feedback of equal or better quality and quantity compared to a paper-based method during class, if the digital system distracts students, and if the digital system provides additional benefits.

We conducted a within-subjects study in a project-based course with 73 students. During two consecutive weeks of project presentations, peers provided feedback either on

paper or through a digital device. To facilitate digital feedback exchange, we used a peer feedback system for web and mobile where students can enter feedback and read/upvote comments written by others. Students provided feedback (either on paper or a device) while the instructors gave verbal feedback, keeping with the culture of this particular course.

Our study examined the quantity and quality of feedback provided with each method, student perceptions of each method, and differences between student and instructor feedback. We found that both methods yielded a similar number of unique open-ended comments, although the digital approach led to more student participation overall when accounting for upvotes. Students generally felt they had better feedback exchanges on paper, although assessments on the feedback by instructors indicated no difference in quality. Surveys and interviews with students revealed split opinions. Students who preferred paper liked the ability to create sketches; others appreciated the social awareness and dynamics afforded by the digital method.

This research contributes: 1) empirical evidence that digital systems can be equally as effective as paper-based methods for eliciting student feedback during class, 2) design implications for peer feedback systems, and 3) a discussion on how classroom culture and student expectations might affect the implementation and use of an in-class peer feedback system.

RELATED WORK

The peer feedback process is valued by researchers and educators because it allows students to get a larger quantity of feedback than if the instructor were the only feedback provider [22]. It also allows students to receive feedback faster than if every student was waiting on the instructor. This is particularly important given that a recent study found peer feedback helped students improve their grades, but only if delivered within a timely manner [13].

Peer feedback also improves student learning. Students who reflect on peer feedback and revise their work improve their self-regulated learning skills [3] and self-assessment abilities [15]. Students who provide feedback can learn to focus on students' work and performance, rather than on the students themselves or their personal characteristics [9]. This process also helps students understand the desired criteria (relevant), compare their actual performance with these criteria (critical), and engage in action that closes this gap (actionable) [16,18]. We use those criteria—relevant, critical, and actionable—as metrics to evaluate the feedback given during this study.

Student and Instructor Feedback

Multiple researchers have shown that novice peer feedback can be as effective as receiving feedback from an expert, such as the instructor. Topping [22] found that peer assessment, where students provide a grade in addition to feedback, can improve student performance at least as

much as instructor feedback. Cho and Schunn [5] used their SWORD system for providing feedback on writing assignments to show that students receiving feedback from a group of novices had greater improvement on their next draft than students receiving feedback from a single expert, perhaps because students consider peer feedback carefully rather than blindly adhering to expert suggestions. Yuan et al [25] found that when students used rubrics to give critiques, their feedback was perceived to be as useful as expert feedback.

While experts have deep domain knowledge, peers have the advantage of sharing the experiences and challenges of the student. Experts often poorly estimate what feedback is most helpful to novices [12], in part because experts tend to reference concepts and information that novices do not yet possess [4]. Peers, on the other hand, share concepts and skills with the student receiving the feedback, as they are at a similar level of expertise [5]. Even if the content of the feedback is less expert, it may be easier for students to process and understand. Peer feedback can therefore supplement expert feedback, as each has different strengths and weaknesses.

Real-Time Technology in the Classroom

Bringing technology into the classroom may reveal challenges related to classroom culture and technology adoption that are not a factor when using paper to collect feedback. Technology can be a distraction to students during class [8], not only to the students using the system, but also to instructors or students who present to an inattentive audience. Instructors may also be hesitant to introduce an unfamiliar technology into a live class [2].

Although many advocate for the benefits of using paper instead of digital or electronic information (e.g. [19]), researchers have started investigating the effects of using digital systems in the classroom. Piper and Hollan [17] found that students were more engaged with educational material presented on a tabletop display than with the same material presented on paper. The study found students who used the tabletop display solved problems on their own before resorting to answer keys and repeated activities more often than students who used paper documents.

Peer Feedback Systems

Most peer feedback systems are designed for use outside of class, typically by requiring students to review a certain number of peer assignments before they receive their own feedback [13]. As demonstrated in prior work, this design choice creates a burden on students to find additional time outside of class and limits the number of perspectives represented in the feedback a student receives [13]. These challenges may be mitigated by an in-class peer feedback system that mimics the process used when providing written feedback during class [20]. The open question that we explore in this research is how in-class digital peer feedback systems compare with other methods.



Figure 1. Screenshot from a game created by students in the final presentation.

METHOD

Participants

We conducted a study with 73 students in a graduate-level project-based course on designing virtual environments and games (see Figure 1 for an example). The instructor divided students into fifteen teams to complete course projects, each lasting around two weeks. Teams were randomized between projects. The course, offered at a mid-western university in the United States, was divided into two sections—one in the morning and one in the afternoon. Students were assigned to present their work in a particular session, but they could also attend the other session to provide feedback, and often did. Each section met for three hours twice a week. All fifteen teams presented designs to the class each week, either as a work in progress or as a finished product. Half of the teams presented in the morning section and half in the afternoon section; in both sections, the entire class session was devoted to presenting work and receiving feedback.

Classroom Setting

Before our comparative study, we observed the class for one week to establish a baseline before introducing the digital system. We also briefly interviewed the two course instructors prior to our observation using a semi-structured interview process to gain insights on their development of the existing peer feedback techniques used in this course.

As part of the regular feedback process in the course, the class used a paper-based system. Before class, the teaching assistants would leave a pile of notecards on each chair in the classroom. Students were expected to write feedback on one notecard per presenting team. Figure 2 shows an example paper notecard. After each student presentation, the course instructors would give public verbal feedback to the presenting team. Students could provide written feedback at any point; there were no restrictions on when they could and could not write. At the end of class, notecards were handed directly to a representative from each presenting team. Instructors and teaching assistants never saw what was written on the notecards, and did not record or grade participation in the feedback process.

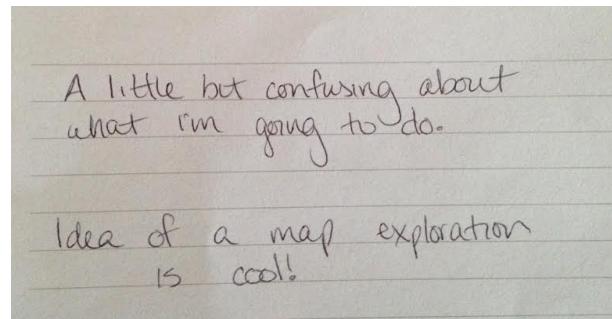


Figure 2. Example of a paper notecard.

Despite the existence of a formal feedback process, the course instructors did not feel students were successfully learning peer feedback skills. Instructors commented that students would not give helpful or high-quality feedback to each other. Further, the instructors felt the teams were not sufficiently reflecting on the instructors' or peers' feedback. One instructor pointed out that they had recently implemented a new assignment to “make them at least read [the feedback]”.

An instructor said that “the class is defined by students showing work off to each other” and that they believe students have a “strong desire to share and discuss what’s being done.” We observed students paying close attention during student presentations, so much so that they would often audibly react to the game demos. After each presentation, instructors would spend up to twenty minutes giving verbal feedback. During this time, students would spend no more than five minutes writing feedback on their notecards, and we observed how students would drift towards Facebook, mobile phones, or other off-topic distractions until the next presentation began. We frequently observed students falling asleep between presentations while instructors were speaking.

The Digital Feedback System

For a digital comparison to the paper feedback process, we used an open source peer feedback system designed to be used in real-time during the class session [20]. With this system, students access presentations on either a laptop or a mobile device using a short sharable link. Students choose a username for each presentation. There are no requirements or restrictions on what can be chosen as a username. Students can type multiple responses into a text box in real-time during the presentation. Students can view and upvote the responses given by other students in real-time on a separate tab of the system interface. Voting students cannot see the author’s username, but that information is available to the presenting team. Afterwards, the presenting team can view all their feedback and sort, tag, and filter comments to organize the feedback received. Screenshots of this system are shown in Figure 3.

Procedure

We implemented a two-week study during the final project. During the first week, the morning section gave feedback on paper, and the afternoon section used the digital system to provide feedback. For the second week, the afternoon section gave feedback on paper, and the morning section used the digital system. Each team presented for about four minutes, followed by 10-20 minutes of instructors' verbal feedback, during which time students provided feedback on paper or through their devices. For these two weeks, if a class section was in the digital condition, the teaching assistant for the course transcribed all the instructors' verbal comments into the digital system for later comparison with student comments. The research team had extra devices available in case students did not have access to technology, but the students never needed them.

Students were given a pre-survey before the study asking their opinions on the paper process, challenges they faced when giving or receiving feedback on paper, and their current process of reflecting on feedback. The pre-survey consisted primarily of Likert-scale questions for agreement: for example, "How much do you agree/disagree with the following statement: I can say everything I want to say using the paper notecards". Students were also given a post survey at the end of the study asking them to compare the paper process to the digital system by reporting perceived

differences between each method with multiple-choice questions (PeerPresents, Notecard Rodeo, or No preference). We also asked students to express their preferences on open-ended questions, which we analyzed to extract themes and interesting comments.

Measures and Analysis

Student Participation

From system logs, we collected the usernames used by students, the responses and timestamps of those responses, and a list of usernames that voted on each response. We collected and transcribed the notecards and counted how many notecards included drawings.

To measure how long students stayed engaged with paper-based peer feedback, a researcher observed two class sessions before the digital system was introduced. The researcher sat such that she could unobtrusively observe all students. The researcher recorded the times when each presentation started, when the majority of students had stopped writing, when all students had stopped writing, and when the instructors stopped talking. Length of engagement with the digital system was computed using system logs.

Figure 3. Screenshots of the digital system. Peers use the “comment interface” (upper left) to provide feedback. Peers can switch to the “upvote interface” (lower left) to review other students’ comments. The “reflection interface” (right) allows presenters to organize their feedback after the presentation.

Feedback Quality

We surveyed students on the perceived quality of the feedback exchange with each method. We also asked students for their opinions on the strengths and weaknesses of each method. Finally, we randomly selected 10 comments each from two digital condition presentations and two paper condition presentations and asked instructors to rate the quality of comments on a scale from 1 to 5. Instructors were blind to condition; the comments were a random sample of 10-15% of comments from 25% of the teams, as instructors were under tight time constraints and could not rate all comments.

Content Analysis

To further investigate the content of written responses, we segmented responses into individual comments and coded them into categories. We divided responses into individual comments primarily based on physical markers such as bullet points or numbers, separate sentences or sentence clauses, and skipped lines between items. We coded feedback into categories based on relevance, form, and sentiment (see [16,18]).

For relevance, comments were coded as On Topic (focused on content), On Topic (focused on communication skills), Emotional Support, or Off Topic. Comments were also coded as either Praise, Criticism, Neither praise nor criticism, or Both praise and criticism. Comments were also coded as Descriptive, Actionable, Question, or None of the above. Descriptive comments were stating observations or describing the game. Actionable comments were offering specific suggestions or giving instructions. Questions were comments where students asked the presenters a question. Table 1 lists examples of each type of comment. Three independent coders categorized 10% of the data and achieved moderate agreement. After discussion and retraining on all categories, coding agreement on an

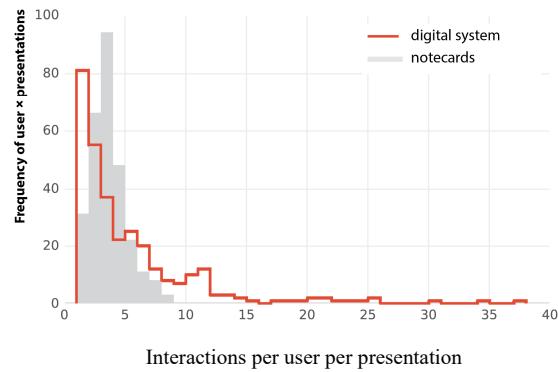


Figure 4. Distribution of interactions per user per presentation shows some students interacted much more with the digital system.

additional 5% of the data reached an acceptable agreement of ICC 0.85.

RESULTS

The overall results show that students wrote a similar number of comments on paper as the digital condition, and instructors rated comments from both conditions to be equal in quality. Students in the digital condition interacted in more diverse ways and for a longer period of time than with paper, despite students expressing a preference for paper.

In both the paper and digital condition, there was an average of 20 respondents per presentation (approximately 2/3 of the class; the other 1/3 chose not to participate). Each respondent gave an average of three comments per presentation (an average of 57 comments per presentation). About half (56%) of students' digital responses received at least 1 upvote. Across all presentations in the digital system, 44% of students were active voters (more than 3 upvotes), and 1 student voted on every presentation but did not provide any written comments. 13% of paper notecards had drawings.

Comment Relevance	On Topic: Content On Topic: Communication Emotional Support Off Topic	“Music could have been more intense” “It's interesting how it's only one person responding to questions, and the same person standing apart from the team...” “Great effort”; “I would love to try your game” “Shooting lasers!!!”
Comment Form	Descriptive Actionable Question None of the Above	“health bar looks like a shield” “Could add sound effect for teacher turning around” “What was the punching/bosing glove? How was it to be used?” “RIP mama bird”
Comment Sentiment	Praise Criticism Neither	“Whoa nice lighting effects” “The animation of policeman doesn't stop at right time” “How to lose the game?”

Table 1. Example comments for each coding category.

No Difference in Number of Comments per Condition

Students produced a similar number of textual comments on paper as they did on their devices (for paper, $M=61.5$ ($SD=18.75$); for digital, $M=53.2$ ($SD=17.42$)), and there was no significant difference between conditions in the average length of comments (for paper, $M=50.07$ ($SD=38.92$); for digital, $M=55.94$ ($SD=48.45$)). There was also no significant difference in the number of comments per presentation (for paper, $M=3.04$ ($SD=1.45$); for digital, $M=2.86$ ($SD=1.85$)). Based on our observations and from our discussions with students, students did not give verbal feedback to other teams at any time outside of class.

No Difference in Quality of Comments per Condition

Based on instructors' blind-to-condition ratings on a scale of 1 to 5, there was no significant difference in comment quality between conditions (for paper, $M=2.7$ ($SD=0.77$); for digital, $M=2.5$ ($SD=0.65$)).

More Ways to Interact in Digital Condition

The digital system provided an additional way for students to interact through upvotes. Figure 4 shows the distribution of interactions per user over time. With the digital system, many students made only one interaction, while one made as many as 37 interactions in one presentation.

Longer Length of Engagement in Digital Condition

In our observations of the paper system, the majority of students began writing comments after the presentation ended and stopped participating in the feedback process within five minutes ($M= 3.75$ minutes ($SD=0.96$)). With the digital system, students stayed engaged longer and spent more time giving comments, as shown in Figure 5, some continuing to comment for more than 20 minutes.

Students Thought Paper Produced More Feedback

On the post survey, students reported feeling that they received more feedback from paper notecards, $X^2(1,N=73)=17.31$, $p<0.05$. Students did not report a significant difference between paper and digital in terms of

what led them to participate more during class, or what led them to give more feedback during class.

Students Perceived Paper Produced Better Feedback

Students believed they gave higher quality feedback on paper, $t(73)=8.33$, $p < 0.05$. Students also believed they received higher quality feedback from paper notecards, $t(73) = 35.0$, $p < 0.05$. However, as noted above, there was no significant difference in comment quality between conditions.

More Content-Related Comments Using Paper

There was a significantly different distribution of comments among relevance categories, $X^2 (3,N=1659) = 55.60$, $p<0.05$ (see Table 2). Students in the paper condition had more On-Topic-Content comments, fewer On-Topic-Communication comments, and fewer Off-Topic comments than students in the digital condition. There were a similar number of Emotional-Support comments, Critical comments, and Actionable comments between conditions.

Faculty Gave More Critical and Actionable Feedback

Instructors gave more relevant comments, less praise, more criticism, and more actionable comments compared to students in either condition (see Table 2). This aligns closely with the prior work's definition of "good" feedback as relevant, critical, and actionable [16,18].

Student Opinions

Open-ended questions on the survey asked students to describe the strengths and weaknesses of each feedback method. Students provided opinions on four key aspects.

Physical Constraints on Paper and Devices

Students said that it was hard to read handwriting on the notecards, and we observed students ignoring cards they could not read in team discussions. Students said it was difficult to write in the dark classroom, and they frequently forgot to bring a pen. Students also believed they ran out of space on the cards.

		Student notecards	Student digital	Faculty
Comment Relevance	On Topic: Content	793 (92.1%)	666 (82.5%)	149 (98%)
	On Topic: Communication	20 (2.3%)	35 (4.4%)	2 (1.3%)
	Emotional Support	43 (5.0%)	33 (4.1%)	1 (0.1%)
	Off Topic	5 (0.5%)	64 (8.0%)	0 (0%)
Comment Form	Descriptive	642 (74.6%)	535 (67.0%)	96 (63.1%)
	Actionable	113 (13.1%)	109 (13.7%)	44 (29.0%)
	Question	75 (8.7%)	91 (11.4%)	12 (7.9%)
	None of the Above	31 (3.6%)	63 (7.9%)	0 (0%)
Comment Sentiment	Praise	406 (47.2%)	311 (39.0%)	30 (19.7%)
	Criticism	227 (26.4%)	200 (25.1%)	53 (34.9%)
	Neither	269 (31.2%)	318 (39.8%)	75 (49.3%)

Table 2. Distribution of comment type for students in each condition and for instructors.

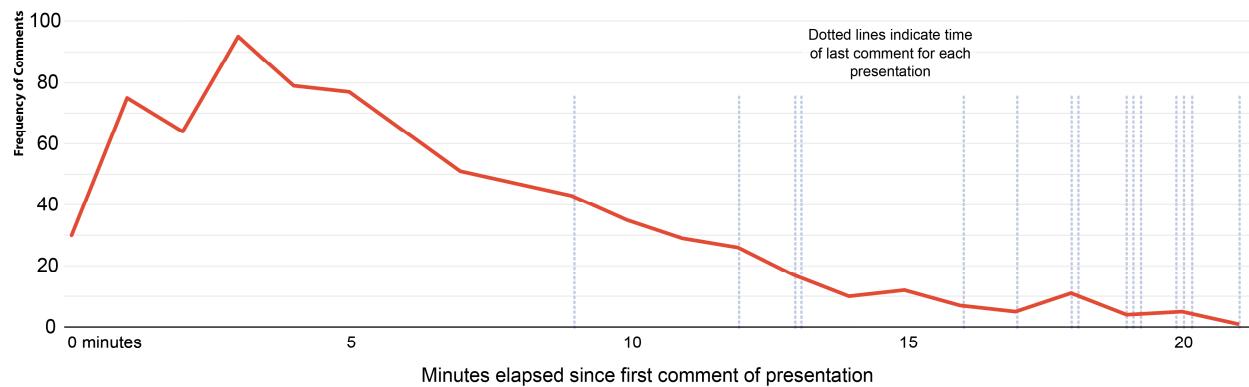


Figure 5. Digital comments peaked around 4 minutes, but continued for up to 20 minutes for some presentations.

When using the digital system, students said that not everyone has a laptop, and the mobile view of the system was not always sufficient. Students expressed the inability to draw as a major shortcoming of the digital system.

Digital Supported a Social Atmosphere

Students felt that the digital system was “fun”, “funny”, and “social.” Students commented that they liked being able to see other students’ opinions during class. However, some students felt the social atmosphere had drawbacks. Students felt the comments turned into more of a group chat than a meaningful critique, and that some students were “performing” by trying to write the funniest or most provocative comments, rather than trying to give the most helpful feedback.

Anonymity and Criticism

A few students commented that they felt uncomfortable being critical when the entire class could see their comments, even when the comment did not have their name on it. Students also disagreed on which method felt more anonymous. Some felt notecards were “completely anonymous”, even though we observed that students often recognized each other’s handwriting and drawing style. Others appreciated that the digital system allowed them to choose an anonymous username, and that the username was only visible to the presenting team.

Organization in Both Conditions

There were dissenting opinions among students about which method better supported feedback organization after class. Some felt notecards were easier to organize because all team members could see them without needing a device. Others preferred the sorting and tagging features provided in the digital system. Others did not organize their feedback with either method.

DISCUSSION

This within-subjects study compared different media—paper and digital—for collecting peer feedback in a classroom setting. We found that contrary to popular opinion, technology does not detract from the peer feedback

process, as long as it is used appropriately. Students wrote a similar number of comments with both methods, and instructors rated comments from both conditions to be equal in quality. Students in the digital condition interacted in more diverse ways and for a longer period of time than with paper. However, students generally preferred the paper notecards, and believed that they received more feedback and gave higher quality feedback on paper than online. Here we discuss the discrepancy between students’ perceptions and reality, the ancillary benefits of going digital, the effects on classroom culture, and the pedagogical affordances of each approach. Finally, we deliberate on the design implications, study limitations, and future work.

Student Perceptions vs. Reality

Students accurately believed that they *gave* the same amount of feedback with each approach. However, they inaccurately believed they *received* more feedback from paper notecards, even though there was no significant difference in the average numbers of comments per presentation between conditions or the average length of comments. Our observations revealed that some students did not bring a device to the team meetings when students discussed their feedback, which may account for this discrepancy. Even though an equal amount of feedback was available, some students may not have seen it.

Students also believed they gave and received higher quality feedback on paper, and that the digital system was more of a social group chat than a meaningful critique. However, the instructors’ ratings indicate no difference in comment quality between conditions. This misconception may be due to the different distribution of comments for each method, as students in the paper condition gave more content-related comments, fewer communication-related comments, and fewer off-topic comments than in the digital condition. This misconception could relate to the students’ perspective that peers were acting like “performers” on the digital system. The public nature of commenting may have

led students to believe they received more off-topic comments than was actually the case.

Ancillary Benefits of the Digital System

Paper notecards and the digital system perform equally well at generating useful comments. However, there are additional advantages to using a digital approach.

Facilitating Diverse Input and Social Interactions

The ability to comment quickly, endlessly, and in real-time seems to have encouraged students to give feedback on in-the-moment observations such as presentation style, which they were less inclined to comment on when using paper, perhaps because of their perception of a limited response space. The digital system allowed students to comment anonymously if they chose, which students valued.

Importantly, the digital system allowed multiple types of interactions during class, a strategy supported by the theory of legitimate peripheral participation [14]. Students who felt less inclined to comment could still participate by reading and voting on other comments. This additional method of participation could explain why students stayed engaged with the digital system for so much longer than observed when writing on the paper notecards.

Students remarked on some negative aspects of the social atmosphere they experienced in the digital system, and there were more off-topic comments in the digital version. We expect this is related to the sense of immediacy the system provides, allowing students to capture their transient thoughts and ideas more easily than when writing feedback on a notecard. When students feel free to respond with what's on their mind, they produce more off-topic comments, but also more comments related to in-the-moment observations such as communication style or points of confusion that might later be resolved.

Providing Organization Support

The digital system offered organization support for students to sort and tag their feedback. While not all students chose to utilize those features, the ones that did found the process valuable to their reflection, which has been shown to be an essential aspect of peer feedback by prior researchers [16].

However, while some teams valued the organization provided by the digital system, the sorting and tagging functionality did not support every team's reflection process. Some teams relied on physically sorting and grouping notecards in a way that could not be captured with the digital system. The digital system had a "Download Responses" button that allowed students to print out their comments, but students did not use this feature.

Handling the Logistics of Peer Feedback

The digital system also provided support for instructors. The system made the logistics of giving and receiving feedback easier, which is a factor teachers value when implementing in-class technology [2]. Teaching assistants did not have to hand out piles of notecards to every chair, team leaders did not have to gather cards from every

student, and feedback was never lost in the way a misplaced notecard would be. In larger classes, the paper notecard process would be unmanageable from a logistics standpoint, but the digital system scales.

Effects on Classroom Culture

The instructors commented on the investment students had in their peers' projects. The faculty believed every student was writing notecard feedback, when really only two-thirds of the class participated on paper. Introducing the digital system did not change the number of participants in class.

The digital system did increase the length of time students were engaged in the peer feedback process, but faculty may have been unaware of this difference. When we observed instructors giving verbal feedback before introducing the digital system, they stood at the front of the room facing the presenters, with their backs to the rest of the class. Thus, they could not see when students became disengaged with the feedback process and turned to Facebook or fell asleep.

It is important to note that giving students a specific task to do on their devices kept their attention on course content for a longer period of time than asking them to put their devices away and comment on paper. Students did not report feeling distracted when using the digital system either as a presenter or as a feedback provider. Using a digital system also did not change the quality of the student feedback. The classroom culture around peer feedback did not significantly change because of our two-week system intervention.

Pedagogical Affordances of Digital and Paper

Although students valued the paper feedback more, instructors should choose a peer feedback system that provides the most pedagogically effective approach for a given classroom context. To understand the pedagogical differences between the paper and digital systems, we examined the affordances each provides. Paper provides better tangibility, spatial awareness, and flexibility [11]. The digital system builds on the affordances of social media, including visibility, editability, persistence, and association [23].

In our study, the tangibility of the paper notecards may have made that feedback more salient to students during reflection sessions. Students valued the flexibility to "break the rules" by providing drawings as feedback. Some groups relied on physically organizing the paper notecards, although it created a burden for the instructors and TAs.

The visibility of the digital system influenced students' social behavior, causing some of them to "perform" for the class. Visibility also allowed people to react to each other's comments by voting. The persistence afforded by the digital system meant students could see comments after the fact, promoting a longer length of engagement with the peer feedback process.

Students responded positively to the tangibility of the physical system, even when it created an extra burden for the instructors and TAs. On the other hand, the visibility of the digital system significantly influenced student behavior in both helpful and potentially distracting ways.

Students engaged with the affordances of each system in ways that revealed their needs in the feedback process. Paper sketching indicates that students desire to be expressive (which was further validated by their survey responses) while the use of upvoting suggests students' desire to be social (which was further validated by their "off-topic" comments in the digital condition). Future work can explore how to accomplish both these goals, as well as increase the quality of peer feedback.

Design Implications for Peer Feedback Systems

Future designs for in-class peer feedback systems can explore how visibility can improve student experience with the system, mitigate the perception of social performance, and increase the quality of peer feedback.

Expressiveness

Students took advantage of having multiple ways to interact with the digital feedback, particularly with low-effort upvotes. Students also enjoyed the social aspect of the system. They missed not being able to give expressive feedback through drawings. Supporting such expressive forms of interaction can help accommodate for a lack of nonverbal cues, a known issue in computer-mediated communication [24]. Future peer feedback systems could design other interactions that allow students to make their social self and emotional state visible in a helpful way. For example, a system could allow students to click on their mood throughout the presentation (confused, bored, engaged, etc.) or even add a meme to give feedback.

Mutual Awareness

In the digital condition, students were highly aware of the audience for comments, which produced concerns about "performing." However, mutual awareness also provided benefits such as the ability to learn from and vote on other students' comments. Future systems could explore more granular control of feedback visibility to support providing good feedback and reflecting on feedback received. For example, other students' comments might only become visible after a student has made a comment themselves.

Modeling Expert Behavior

In our study, instructors gave more criticism, less praise, and more actionable comments than students. Prior research has noted that students benefit from being more critical of each other when giving feedback [10]. However, listening to an expert give good feedback is not enough for students to improve their feedback skills. Future systems could explore other ways to model expert behavior and encourage relevant, critical, and actionable comments from students. For instance, many recent peer feedback systems explore the use of expert rubrics to scaffold the process [13,25]. Another idea would be to delegate to a student or a teaching

assistant the job of transcribing the instructors' verbal comments, making them visible and available for further discussion in the digital system.

LIMITATIONS

The course setup provided constraints for our experiment design. We chose a within-subjects experiment because students could attend both the morning and afternoon sessions of the course. A between-subjects design would have required half the class to use only paper and half to use digital within the same session. This would have made it difficult not only for the instructors to manage, but also for the presenting students to reflect on feedback coming from both notecards and the system. Since both methods (paper and digital) supported anonymity, we were not able to perform within-subjects analysis on an individual basis.

In addition, while we did ask students to rate their feedback as a whole, we did not ask students to individually rate the quality of feedback they received. This information could have been valuable, and we intend to collect student ratings of individual comments in future studies. Future studies should also ask instructors to rate all comments rather than only a subset to better compare to student perspectives.

Finally, our system was deployed for only two weeks, which means that the novelty of the system may have affected our results. Future studies can explore how practices evolve in a digital feedback system over time.

FUTURE WORK

We chose to compare the digital system to a written feedback process rather than a verbal feedback process because written feedback is given in parallel, asynchronously, and in real time, which is more similar to the digital system than a verbal feedback process. This choice also allowed us to examine specific processes only available in the digital system, such as voting on other students' comments. In the future, we would like to make additional comparative evaluations of in-class peer feedback systems to better understand affordances of different in-class peer feedback approaches. For example, the digital system used in this study or another system could be compared to a verbal feedback process, such as a Q&A period. We also want to compare our in-class peer feedback system to a traditional out-of-class peer feedback system.

Digital feedback systems also provide a platform for future interventions. Additional comparisons could be done with versions of this digital system to discover effective interventions, or to mitigate the negative aspects of a social atmosphere. For example, we could make variations of the interface that encourage different levels of awareness of other student comments to see the effects of prioritizing commenting or voting in different educational settings.

We could also use the digital system to investigate attention management during class. Students in this study were more likely to remain attentive to course material when they were given a specific digital task. Future tools could investigate

what tasks help students remain attentive, how long additional tasks can keep students' attention, how students decide when to disengage from the class, and what makes digital tasks more appealing than paper tasks.

Finally, future studies can explore methods for scaffolding peer feedback to look more like expert feedback. For example, we could investigate how to help students frame their own questions as part of a rubric. Another angle is to examine whether different levels of anonymity might encourage more critical feedback.

CONCLUSION

This research presented empirical evidence that shows digital methods can be at least as effective as paper at encouraging student interaction during class while offering logistical benefits for instructors. This work also indicates that students and professors may be overrating the benefits of paper-based feedback and overestimating potential negative effects of technology during class. We also developed design implications for in-class peer feedback systems to enable more expressiveness, to model expert behavior, and to explore different levels of awareness. We also discuss how factors such as classroom culture and student expectations might affect the implementation of an in-class peer feedback system to guide future designers of such systems.

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